

## **SPECIFICATION**

### **1. Title of the Invention**

**Scanning Probe and Manufacture of the Same**

### **2. Claims**

(1) A scanning probe, characterized by being equipped with a piezoelectric substrate, multiple conductive thin film electrodes formed on two opposing surfaces of said piezoelectric substrate, and probes provided on each of said multiple conductive thin film electrodes formed on either one of said two surfaces.

(2) A method for manufacturing the scanning probes according to claim 1 in which probes are formed on each of a number of conductive thin film electrodes formed on either surface of the piezoelectric substrate, said method for manufacturing scanning probes characterized by having a process in which a selective resist mask is formed on each of the probes formed by selective growth and a process wherein said selective resist mask is used in order to taper-etch said probes, thereby making said probes pointed.

### **3. Detailed Description of the Invention**

**[Object of the Invention]**

**(Field of Industrial Utilization)**

The present invention relates to a scanning tunnel microscope and evaluative devices used in supporting technologies, and in particular, relates to a scanning probes and methods for their manufacture.

**(Prior Art)**

In 1982, G. Binnig and H. Rohler developed the scanning tunnel microscope ("STM" below; Phys. Rev., Lett. 49 (1) 57 (1982)), and in the years since that time, many

researchers and persons skilled in the art have developed devices and expanded the field to produce novel evaluative technologies that have capacities for high spatial resolution (IBM J. RE. Develop. 30(4), 355 (1986)).

Scanning probes used in STMs and other supporting devices ("SXM's" below; including interatomic force microscopes and magnetic force microscopes) have generally had pointed tips produced by electrolytically polishing tungsten (W) or platinum (Pt) wires.

On the other hand, in spite of the desire for improved measurement throughput and scanning range, scanning is limited to the range of a few micrometers at the most with simple wire probes, and throughput decreases greatly when the attempt is made to expand the measurement range. For this reason, the introduction of multiple probes is desired, but it is extremely difficult to align wire probes with sufficient precision and to accurately set their positions so that they are at the same height.

(Problems to be Solved by the Invention)

The present invention was developed in light of the above considerations, and has the objective, firstly, of offering a scanning probe that comprises multiple probes that are arranged at uniform height and with precise positioning, and also has a capacity for adjustment of the height of each probe. The present invention has the second objective of offering a manufacture method whereby the scanning probes can be produced easily and with high precision.

(Constitution of the Invention)

(Means for Solving the Problems)

The first defining characteristic of the present invention relates to a scanning probe produced by selectively forming multiple conductive thin film electrodes on two opposing surfaces of a piezoelectric substrate and then providing multiple probes with pointed tips

composed of conductive material on the conductive thin film electrodes of the side on which the probes are to be formed.

The second defining characteristic of the present invention relates to a method for manufacturing the above scanning probe based on selective growth technologies and fine processing technologies in the semiconductor field, where a selective resist mask is used on each of the probes formed by selective growth in order to taper-etch them, thereby making each of the probes pointed.

Specifically, the present invention is characterized in that, simple technologies based on LSI manufacture technologies can be used in order to produce scanning probes with multiple probes used in SXMs (scanning probe microscopes), examples of which include STMs.

#### [Action]

By means of the present invention, a scanning probe having multiple probes can be produced with good layout precision and uniform height within 1  $\mu\text{m}$ . In addition, because a piezoelectric substrate and conductive thin film electrodes formed on the opposing surfaces thereof are employed in the constitution of a precision-drive voltage actuator, each of the probes can be adjusted in terms of their respective distances with respect to the sample. Consequently, isolated servo functionality in the Z direction can be realized with each of the probes in a comparatively small unit, so that the multiprobe STM structure can be simplified while also allowing independent measurement to be carried out with each of the probes.

#### (Working Examples)

Details of the present invention are discussed below using the working example shown in the figures.

Figure 1(a) and (b) respectively present a cross-sectional view and a plan view of the scanning probe pertaining to a working example of the present invention. Figure 1(a) shows a partial cross section between P and Q in Figure 1(b). Details regarding each of the

components in Figure 1(a) are discussed in the manufacture method described below. In this working example, four probes are laid out in such a manner that the respective probe pads are determined by the lead electrodes A1-A4 as shown in Figure 1(b). A prescribed potential can be supplied to the electrodes on one side of the piezoelectric body substrate (in this case, lead titanate zirconate ferroelectric material) via the electrode. Regarding the opposing electrodes on the back surface of the piezoelectric body substrate, on the other hand, the locations are determined by the lead electrodes B1-B4. Consequently, the piezoelectric body substrate contracts and expands in the vicinity of each of the probes in accordance with voltage applied between the respective groups of opposing electrodes A1-A4 and B1-B4. When an uneven sample surface is scanned, this contraction and expansion leads to respective servo capacities for each of the probes (servo control circuits not shown in figure), thus allowing independent upwards and downwards movement of the probes T1 and T2 in accordance with the unevenness of the sample surface (Figure 2).

The method for manufacturing scanning probes of the working examples in Figure 1 is described in detail below in reference to Figure 3(a) to Figure 3(k). First, as shown in Figure 3(a), platinum (Pt) conductive thin film electrode material 2 is vapor deposited at a thickness of about 0.2  $\mu\text{m}$  on both surfaces of a lead titanate zirconate ferroelectric substrate 1. In addition, a silicon oxide film 3 used as an insulating film is then grown by CVD (chemical vapor deposition) at a thickness of about 0.3  $\mu\text{m}$  on the surface on which the probes are to be formed. Next, as shown in Figure 3(b), an electrode pattern of squares of about 20  $\mu\text{m}$  is formed using a photoresist 4 on both of the opposing surfaces by mean of a photolithographic technology, and as shown in Figure 3(c), this material is then used as a mask and the silicon oxide film 3 is selectively removed by etching (e.g., ammonium fluoride treatment). Next, using the same mask, the platinum 2 on both surfaces of the electrode material is removed by etching (e.g., aqua regia treatment or ion milling). As a result of etching, electrodes 2A and 2B including lead electrodes are formed under the resist mask 4, with silicon oxide film 3A formed on 2A. The unwanted resist mask 4 is then stripped, whereupon organic insulating film 5 (e.g., polyimide) is formed on both surfaces to cover the exposed ferroelectric body. As shown in Figure 3(d), a new resist mask 6 is then used in order to selectively etch part of the silicon oxide film 3A (ammonium fluoride treatment or plasma etching) in order to form holes 3C.

Next, as shown in Figure 3(e), the unwanted resist mask 6 is stripped, whereupon polycrystalline film 7 is vapor deposited at about 0.5  $\mu\text{m}$  over the entire surface of the side on which the holes 3C have been made, including the holes 3C. Subsequently, a resist mask 8 is formed that includes the electrode pattern and the electrode pattern that will serve as the probe pads, and the polysilicon film 7 is then selectively removed by etching (e.g., plasma etching) using this resist mask 8. As shown in Figure 3(f), after stripping the unwanted resist mask 8, the probe pad electrodes 7A are present on the electrodes 2A. Next, as shown in Figure 3(g), a resist mask 9 (e.g., photosensitive polyimide film) is formed at sufficient thickness of a few micrometers to about 10  $\mu\text{m}$  having openings 7C in the region of the electrodes 2A and probe pad electrodes 7A.

Selective growth of conductive material (e.g., tungsten) 10 is then carried out in the deep opening regions, thereby filling the openings (Figure 3(h)). Next, selective resists 11 having exactly the same dimensions as the filled openings are formed only in the probe growth regions, as shown in Figure 3(i). The resist 11 is then used as a mask, and reactive ion etching using chlorine-based gas is carried out in order to taper the tips of the tungsten 10 utilizing recession of the resist mask 11. Probes having sharp protruding forms are thus produced. Upon removing the resist mask 11, reaction ion etching is completed (Figure 3(j)), and the remaining thickness of the resist mask 9' is removed at this time by stripping using organic solvent treatment or oxygen plasma treatment, thereby exposing the organic insulating film 5. If the tungsten probes and the lead electrode region surfaces are covered with oxide film at this time, then it is desirable to perform surface reformation by means of treatment with fluorine-based plasma (Figure 3(k)).

The distance between the probes in the working example of the present invention is on the level of a few hundred micrometers (Figure 1(a)). It is possible, however, to drive the precision-drive voltage actuators with good precision at smaller distances, and good precision is conceivable even at 10  $\mu\text{m}$ , for example. Although a lead titanate zirconate ferroelectric body was used as the piezoelectric substrate, there are no particular restrictions on this material. For example, it is possible to use any existing ferroelectric material such as barium titanate systems. Moreover, expansion and contraction of the piezoelectric substrate is approximately a few hundreds of angstroms to 1  $\mu\text{m}$ , and for example, it is desirable to increase the thickness of the piezoelectric substrate in order to increase the degree of contraction and expansion. Consequently, selection of the ferroelectric material

is not of particular importance. In this working example, the electrodes that include the lead electrodes are formed on the substrate, the probe pad electrodes are formed thereupon, and the probes are then formed on the probe pad electrodes. However, it is also possible for the electrodes that include the lead electrodes to function as barriers. Specifically, the probe pad electrodes are composed of polycrystalline silicon, and thus there are cases where the silicon forms a mixed crystal state with the lead titanate zirconate ferroelectric material, thus impeding piezoelectric characteristics (e.g., decreasing the piezoelectric constant by as much as 20-30%). The reaction layer in which this mixed crystal has been generated extends into the ferroelectric body at a thickness of a few tens of micrometers from the interface. Consequently, although effects will be produced if the ferroelectric body substrate reaches a thickness of 100  $\mu\text{m}$  or less, there will be no substantial effects provided that the thickness exceeds 200  $\mu\text{m}$ . Degradation of piezoelectric characteristics resulting from this mixed crystal is also present, with a certain degree of variation, among other materials such as barium titanate systems, and electrodes that employ platinum and the like are inserted between the substrate and probe pad electrodes primarily in order to prevent this mixed crystal from developing. In this working example, platinum was used as the electrode, but materials are not restricted to platinum, and any material may be selected, provided that it is a metal that does not generate mixed crystal with silicon. Silver is an example of such a material. Electrodes produced by baking silver paste are particularly well known in their use in ultrasonic oscillator elements. The electrodes must be in close contact with the piezoelectric substrate, but an effective means for improving adhesive strength is a method in which a thin film of chrome or titanium is inserted between the platinum or silver and the piezoelectric substrate. In order to improve the adhesive strength of silver, a small amount of glass component such as silica or boron oxide is intentionally added, which allows the utilization of mixed crystal production.

In this working example, an example was presented wherein an organic thick film was used in the selective growth of tungsten, but selective growth of tungsten can also be carried out by means of selective beam irradiation in a tungsten hexafluoride atmosphere (e.g., electron beam spot irradiation). In such a case, sharpening of the tops can be carried out simultaneously, and thus it is not necessary to use an organic thick film with holes in order to perform selective growth, making the selective resist mask shown in Figure 3(i) unnecessary. Methods that employ beam irradiation and methods that employ organic thick films of the type described above are both effective in producing the scanning probe

of the present invention having multiple probes, and the dramatic effects of the type obtained with the present invention are realized even when used in the production of scanning probes having single probes.

The evaluative device pertaining to the present invention is targeted towards semiconductor substrates such as silicon, but other examples that may be cited include photomasks. For example, the device can be used in the detection and measurement of defects through observation of surface conditions of chrome mask patterns on masked substrates.

A case involving utilization of the present invention in STM devices was described above, but the method, of course, is also suitable for use in AFM and MFM devices that employ scanning probes, provided that the scope of the invention is not superceded.

#### [Effect of the invention]

By means of the present invention as described above, multiple probes can be utilized as separate measurement probes, and measurement of multiple points can be realized simultaneously as scanning progresses, thus substantially increasing scanning ranges and, specifically, allowing real improvements in measurement throughput. The scanning probe described above also can be produced easily and with high precision.

#### 4. Brief Description of the Figures

Figures 1(a) and 1(b) respectively present a partial cross-sectional view and a plan view of the basic constitution pertaining to the working example of the scanning probe of the present invention. Figure 2 is a schematic diagram that presents the relationship between the measurement sample and scanning probe when the present invention is used in an STM scanning probe. Figures 3(a) to 3(k) present a working example of the process for manufacturing the scanning probe of the present invention.

1      Piezoelectric substrate

2 Conductive thin film electrode material (platinum)

2A, 2B Electrodes including the lead electrodes

3, 3A Insulating film (silicon oxide film)

4, 6, 8, 9, 9', 11 Selective resist mask

5 Organic insulating film (polyimide)

7 Polycrystalline silicon film

7A Probe pad electrode

7C Resist mask opening

10 Selective growth probe material (tungsten)

T1, T2 Probes

A1-A4, B1-B4 Lead electrodes

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